DISCOVERY LIMITS FOR EXTRA GAUGE BOSONS IN $e^+e^- \to \nu\bar{\nu}\gamma^a$

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We study the sensitivity of the process $e^+e^- \to \nu\bar{\nu}\gamma$ to extra gauge bosons, particularly W' bosons. Depending on the model, evidence for extra W bosons in this process can be detected for W' masses up to several TeV.

1 Introduction

Extra charged and neutral gauge bosons are a feature of many models of physics beyond the standard model [1]. If discovered they would represent irrefutable proof of new physics, most likely that the Standard Model gauge group must be extended. Indirect limits exist on extra gauge bosons from precision electroweak measurements and direct limits from searches at high energy colliders, with the highest current limits from the Tevatron Collider at Fermilab [2]. The Large Hadron Collider at CERN will extend the search for W''s and Z''s to several TeV [1]. Precision measurements of cross sections and asymmetries for $f\bar{f}$ final states in high energy e^+e^- collisions can reveal evidence for Z''s ranging from several TeV to tens of TeV depending on the model [1]. However, there are no analogous limits for W''s.

Hewett suggested that the process $e^+e^- \to \nu\bar{\nu}\gamma$ is sensitive to extra W bosons in addition to Z''s [3]. The standard model reaction proceeds via s-channel Z exchange and t-channel W exchange. In extended models the amplitudes are modified by both s-channel Z' and t-channel W' exchange.

In this contribution we present the expected discovery reach of this process for several models with extended gauge groups. We also consider the sensitivity of our results to different luminosities and to a small systematic error.

We considered a number of models with W''s. The Left-Right Model (LRM) [4] is based on the gauge group $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$ giving rise to a W' and a Z'. The W' is right handed and we assume massless Dirac neutrinos. The model is parametrized by the ratio of the coupling constants of the two $SU(2)$ gauge groups, $\kappa = g_L/g_R$, which we vary over the range $0.55 \lesssim \kappa \lesssim 2.0$ [3,5]. $M_{Z'}$ and $M_{W'}$ are related by $M_{Z'}^2/M_{W'}^2 = \rho\kappa^2/(\kappa^2 - \tan^2\theta_W)$ where ρ describes the Higgs content of the model. We assume $\rho = 1$, corresponding to Higgs doublets. The Un-Unified Model (UUM) [6] employs the gauge symmetry $SU(2)_q \times SU(2)_l \times U(1)_Y$, with left-handed quarks and leptons transforming as doublets under their respective $SU(2)$ groups. We parametrize the UUM by an angle ϕ, which represents the mixing of the charged gauge bosons of the two $SU(2)$ groups, and by $M_{W'}$, taken to be equal to $M_{Z'}$. The existing constraint on ϕ is $0.24 \lesssim \sin\phi \lesssim 0.99$ [7]. Kaluza-Klein Excitations

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(KKM) exist in models containing large extra dimensions [8]. The fermion coupling of the first KK excitations is enhanced by a factor of $\sqrt{2}$. Finally we include Sequential Standard Models (SSM) which are not true models but have become a standard benchmark used to compare the discovery reach. We consider a SSM W' with no Z' (SSM1) and a SSM with both a Z' and W', of equal mass (SSM2).

2 Calculation and Results

The process we are studying is

$$e^+e^- \rightarrow \gamma\nu\bar{\nu} \qquad (1)$$

where the neutrinos only manifest themselves as missing energy and momentum. The process is described by the Feynman diagrams of Fig. 1.

Calculation of the cross section is relatively straightforward. We did the calculation in a number of ways to give us independent checks. As input, we take $M_W = 80.33$ GeV, $M_Z = 91.187$ GeV, $\sin^2\theta_W = 0.23124$, $\alpha = 1/128$, $\Gamma_Z = 2.49$ GeV.

Figure 1: The Feynman diagrams contributing to the process $e^+e^- \rightarrow \nu\bar{\nu}\gamma$

We included the following kinematic cuts to reflect finite detector acceptance: $E_\gamma > 10$ GeV and $10^o \leq \theta_\gamma \leq 170^o$ where θ_γ is the angle of the photon relative to the beam. Our process is relatively background free with the most dangerous background coming from Bremsstrahlung events of Bhabha-scattering with the electron and the positron lost down the beam pipe. This background can be eliminated by the kinematic constraint $p_T^\gamma > \sqrt{s}\sin\theta_\gamma\sin\theta_v/(\sin\theta_\gamma + \sin\theta_v)$ where θ_v is the minimum angle for veto detectors to observe activity; we take $\theta_v = 25$ mrad.

Fig. 2 shows the total unpolarized and 100% left and right polarized cross sections (σ_L and σ_R) for the SM, LRM ($\rho = \kappa = 1$), UUM ($\sin\phi = 0.6$), SSM and KK models, all with $M_{W'} = 750$ GeV. The peaks are due to Z''s. At large $\sqrt{s}$ the t-channel dominates so, for right-handed polarization, the LRM exhibits the largest deviation from the SM. Polarization will be seen to be an important tool for discriminating between models and to constrain couplings. The enhanced couplings of the KKM yield striking results in general.

Fig. 3 shows the differential cross section, $d\sigma/dE_\gamma$, for 100% polarized electrons and $\sqrt{s} = 500$ GeV. To gauge the relative statistical significance of the different kinematic regions we plot the deviations between the SM and extended model differential cross sections divided by the square root of the SM differential cross section (which is proportional to the statistical error and would be normalized by the integrated luminosity). The peak at large E_γ is due to the radiative return to the Z^0 and is insensitive to extra gauge bosons. To eliminate the Z^0 peak, which contributes nothing to the sensitivity to W''s and Z''s, we impose the additional cut $E_\gamma^{max} < \frac{\sqrt{s}}{2}(1 - M_{Z^0}^2/s) - 6\Gamma_{Z^0}$.
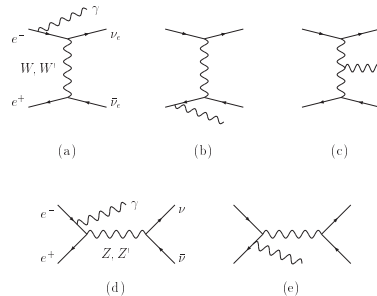
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Fig. 3 further demonstrates the importance of polarization for W' searches. For example, the LR model has right-handed couplings and so does not deviate significantly from the SM for left-handed polarization but does for right-handed polarization. In contrast, a left-handed SSM W' contributes only to σ_L while the KK model contributes to both. Note that the right-handed cross sections are significantly smaller in magnitude than the left-handed cross sections. So although the deviations are far more pronounced for right-handed couplings, they are not necessarily more statistically significant for polarization below 100%. The large difference between σ_L and σ_R also means that unpolarized cross sections are dominated by the left handed contributions.

We examined a number of observables: total cross section, σ_L and σ_R, Left-Right asymmetry (A_{LR}), Forward-Backward asymmetries, and binned photon energy and photon angular distributions. Generally, the $d\sigma/dE_\gamma$ distributions for polarized e^- were most sensitive to new gauge bosons. However, in many cases the total and polarized cross sections with the E_γ cut and A_{LR} were comparable in sensitivity. We considered two integrated luminosities to see how the limits varied. We obtained limits by calculating the χ^2 from the difference between the

Figure 2: The cross section versus $\sqrt{s}$ for several models for unpolarized (top), right-handed (middle) and left-handed (bottom) e^- beam.

extended model and the standard model and dividing by the statistical error assuming the non-standard cross section was measured. We found limits based on the statistical errors alone and then included a 2% systematic error combined in quadrature with the statistical error. Finally, we considered 100% and 90% electron polarization. One sided 95% C.L. discovery limits for the various models, assuming 90% polarization, are summarized in Table 1 for $\sqrt{s} = 0.5$, 1.0, and 1.5 TeV with the integrated luminosities given in the table. We present the discovery limits for the polarized cross sections. In the cases that the energy distribution was most sensitive, the discovery limit difference was about 50 GeV.

Depending on the model, the search reach for W''s can be quite substantial, especially for the high luminosity scenario. However, including even a relatively small systematic error of 2% reduces the limits from the total cross sections substantially. The limits obtained from the energy distribution were not degraded nearly as much
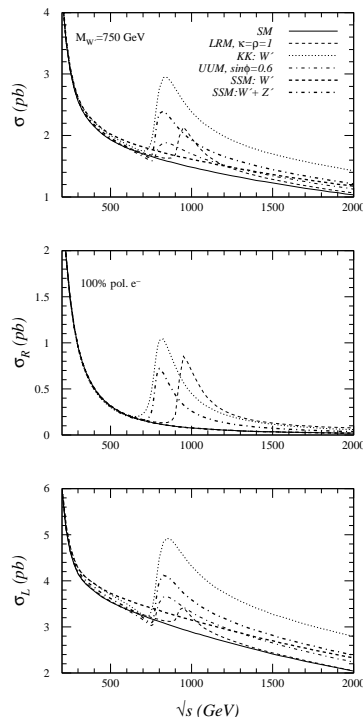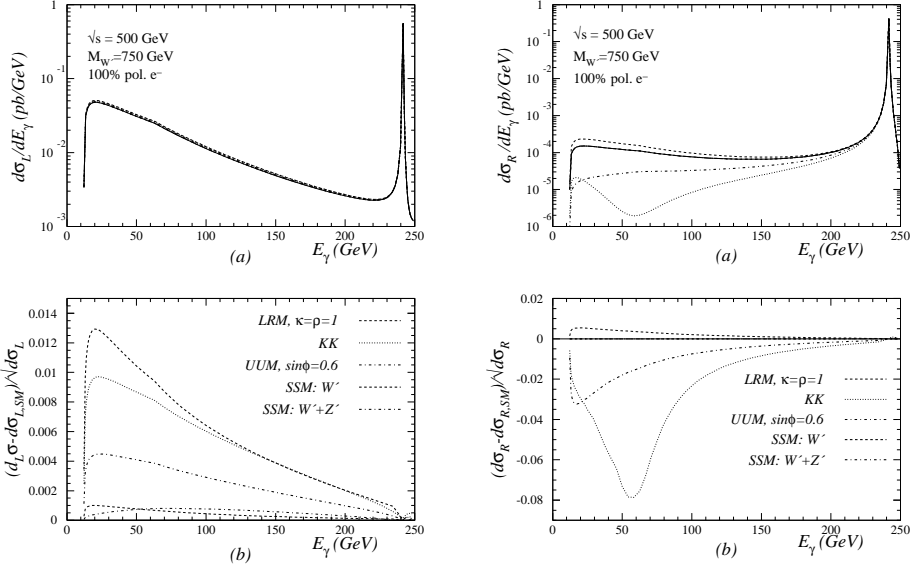
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Figure 3: The Left and Right polarized differential cross sections (top) and the relative statistical significance of the deviation from the SM (bottom) versus photon energy.

by the systematic error. However, our results which include systematic errors for distributions can only be considered approximate without a proper detector simulation. It is clear that systematic errors as large as 2% are likely to dominate as, once they are included, both luminosities lead to similar limits. We also note that for several cases σ_R with 100% polarization yields the highest limits. However, with 90% polarization σ_L generally yields the highest limits. This is a consequence of the larger left-handed cross section dominating the right-handed cross section with even a small pollution of e_L^- in the e_R^- beam. To some extent this can be overcome by polarizing both the e^- and e^+ beams, effectively increasing the net polarization.

3 Summary and Outlook

In this contribution we demonstrated the usefulness of the process $e^+e^- \to \nu\bar{\nu}\gamma$ for W' searches. The results are sensitive to the models so that, if there is evidence for an extended gauge sector, this process could be used to help identify the model. In particular, an analysis of $Z'\nu\nu$ couplings and W' identification will be presented in a forthcoming publication.

References

Table 1: W' 95% C.L. discovery limits obtained in the SSM1 (W'), SSM2 (W' and Z'), LRM ($\kappa = \rho = 1$), UUM ($\sin\phi = 0.6$), and the KKM. We assume 90 percent e^- polarization and use 1/2 the stated unpolarized luminosity for the left and right cases.

$\sqrt{s}$ (GeV)	Model	Observable	50 fb^{-1}	500 fb^{-1}	50 fb^{-1} + 2% sys	500 fb^{-1} + 2% sys
500	SSM1	σ_L	2.4	4.25	1.0	1.0
	SSM2	σ_L	1.80	3.25	0.5	0.5
	LRM	σ_R	0.8	1.25	0.7	0.75
	UUM	σ_L	0.6	2.0	0.55	0.55
	KKM	σ_L	2.60	4.65	1.0	1.0
1000			200 fb^{-1}	500 fb^{-1}	200 fb^{-1} + 2% sys	500 fb^{-1} + 2% sys
	SSM1	σ_L	4.15	5.25	1.25	1.25
	SSM2	σ_L	3.15	4.1	0.95	0.95
	LRM	σ_R	1.35	1.6	1.05	1.05
	UUM	σ_L	1.2	2.35	1.05	1.05
	KKM	σ_L	4.55	5.75	1.0	1.0
1500			200 fb^{-1}	500 fb^{-1}	200 fb^{-1} + 2% sys	500 fb^{-1} + 2% sys
	SSM1	σ_L	4.65	5.8	1.45	1.45
	SSM2	σ_L	3.45	4.45	1.45	1.45
	LRM	σ_R	1.7	1.9	1.4	1.45
	UUM	σ_L	1.75	1.8	1.4	1.4
	KKM	σ_L	5.05	6.45	1.45	1.45

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